Seizure (2005) **14**, 541—551

ELSEVIER

SEIZURE

www.elsevier.com/locate/yseiz

Resection extent versus postoperative outcomes of seizure and memory in mesial temporal lobe epilepsy

Eun Yeon Joo [a], Hyun Jung Han [e], Eun Kyung Lee [a], Sujung Choi [a], Ju Hee Jin [d], Jee Hyun Kim [a], Woo Suk Tae [a], Dae Won Seo [a], Seung-Chyul Hong [b], Munhyang Lee [c], Seung Bong Hong [a,*]

[a] *Department of Neurology, Samsung Medical Center and Center for Clinical Medicine, SBRI, Sungkyunkwan University School of Medicine, 50 Irwon-Dong, Gangnam-Gu, Seoul 135-710, Korea*
[b] *Department of Neurosurgery, Samsung Medical Center and Center for Clinical Medicine, SBRI, Sungkyunkwan University School of Medicine, Seoul, Korea*
[c] *Department of Pediatrics, Samsung Medical Center and Center for Clinical Medicine, SBRI, Sungkyunkwan University School of Medicine, Seoul, Korea*
[d] *Neuropsychological laboratory, Samsung Medical Center and Center for Clinical Medicine, SBRI, Sungkyunkwan University School of Medicine, Seoul, Korea*
[e] *Department of Neurology, Myongji Hospital, Kwandong University, Goyang City, Korea*

Received 17 May 2004

KEYWORDS
Temporal lobe epilepsy;
Surgery;
Anterior temporal lobectomy;
Hippocampus;
Neocortex;
Outcome;
Memory

Summary

Objectives: To investigate the effects of the resection of hippocampus and temporal neocortex on postsurgical seizure and memory outcomes in mesial temporal lobe epilepsy (mTLE) patients.
Methods: Sixty-eight mTLE patients underwent pre- and postsurgical brain magnetic resonance imaging (MRI). The patients were divided into seizure-free group (SF, $N = 54$) and non-seizure-free group (NSF, $N = 14$). The resection length of hippocampus was determined by the difference between presurgical and postsurgical hippocampus lengths in MRIs. The lengths of resected temporal gyri were measured on three-dimensional MRI reconstruction. Among SF group, 37 patients performed pre- and postsurgical neuropsychological tests. The postsurgical memory decline (PMD) was calculated by subtracting postsurgical memory score from presurgical one in verbal and visual memory tests.
Results: The resection length of hippocampus in SF was significantly longer than in NSF (32.7 ± 7.7 mm versus 25.1 ± 7.3 mm, *t*-test, $p = 0.002$), regardless of

* Corresponding author. Tel.: +82 2 3410 3592; fax: +82 2 3410 0052.
E-mail address: sbhong@smc.samsung.co.kr (S.B. Hong).

doi:10.1016/j.seizure.2005.08.011

intersubject difference in the extent of hippocampal sclerosis (logistic regression, $p = 0.003$) while the resection lengths of the lateral temporal gyri were not different between SF and NSF. Overall postsurgical change of verbal or visual memory was not significant. However, regression analysis showed a significant correlation between the resection length of inferior or basal temporal gyrus and verbal PMD ($p < 0.001$) in left TLE patients with seizure-free outcome.
Conclusion: More resection of hippocampus may predict a better postsurgical seizure-free outcome. The larger resection of inferior or basal temporal gyrus seems to be related to a postsurgical verbal memory decline in left TLE patients.

Introduction

Seizures arising from the temporal lobe are the most frequent type of medically intractable seizures.[1] There is no agreement on the relationship between the resection extents of mesial and lateral temporal structures and postoperative seizure outcome. Several studies reported the positive correlation between a good surgical outcome and the resection extents of mesial temporal structure.[2–4] However, other studies showed no difference in postoperative seizure outcome between the patients with minimal resection of hippocampus during anterior temporal lobectomy and those with major amygdalohippocampectomy.[5,6]

Memory dysfunction is the most important neuropsychological characteristic of patients with hippocampal sclerosis. Numerous studies suggest that patients with the left hemisphere speech dominance and the left mesial TLE exhibit the dysfunction in verbal memory.[7] The association between right mesial TLE and nonverbal memory deficits, on the other hand, is less definite.[8]

In the electrocorticography (ECoG) of mesial TLE patients during the operation, interictal spikes were frequently observed in the lateral temporal neocortex.[3] No correlation was reported between residual spikes on postresection ECoG and postsurgical seizure outcomes.[9,10] Also, some authors recommended the resection of the amygdalohippocampal complex while preserving the functional association areas of the lateral temporal cortex, including speech and visual spatial function.[11] However, others insisted the importance of resection of lateral temporal neocortex for preventing the propagation of epileptic discharges during TLE seizures.[12] The consensus regarding the effect of the extent of the resection of the lateral temporal neocortex on the postoperative memory has not been reached yet.[13,14]

These contradictory results may be derived from various techniques used to measure the resection extents of temporal lobe and different surgical approaches. Although many studies using MRI have been tried, differences in the method and the patient population could produce the different results.[3,4,15,16]

The aims of this study were to investigate whether the resection lengths of the hippocampus and the lateral temporal gyri measured by MRI reconstruction method affect the postsurgical seizure outcome and the postsurgical memory in mesial TLE patients.

Methods

Patients

We recruited, consecutively, 95 patients who met the following inclusion criteria as mesial TLE: (1) a temporal epileptic focus with typical complex partial seizures by a long-term video-EEG monitoring, (2) hippocampal atrophy or sclerosis without other structural abnormality on brain magnetic resonance imaging (MRI). All subjects underwent Wada test to determine the dominance of language and memory and presurgical brain MRI. All were medically intractable to two or more anti-epileptic drugs (AEDs) for a long period (5–22 years). When the available data failed to provide a convergent lateralization of the epileptic focus, bitemporal depth or strip electrodes were implanted to determine the resection side (10 of 95 patients). Ninety of 95 patients had undergone the anterior temporal lobectomy with amygdalohippocampectomy at the Samsung Medical Center from 1997 to 2001.

In consideration of brain MRI finding (extents of hippocampal atrophy and sclerosis), the Wada test and ECoG, the resection length of hippocampus was determined as complete or partial (ranged from 30.5 to 100%). The *complete* resection of hippocampus refers to the extent of resection in which posterior part of the hippocampal formation nearby the fasciolar gyrus is not visualized on the serial coronal images of postsurgical MRI. If the tail of hippocampus remained in postsurgical MRI, it is referred to as the *partial* resection of hippocampus.

Usually anterior temporal lobe of 3 cm from temporal pole was resected both in left and right

TLE, but there were some variations according to Wada memory result and ECoG. Wada memory scores (WMS) were defined as a number of items remembered correctly in a choice recognition memory test at 10 min after amobarbital injection and presentation of 12 memory items to the patient.[17,18] Wada memory asymmetry index was calculated by (WMS of normal hemisphere − WMS of epileptic hemisphere)/[(WMS of normal hemisphere + WMS of epileptic hemisphere)/2].[17]

Temporal neocortex adjacent to resection margin showing frequent spikes on ECoG was also resected. If memory function on Wada test was not decreased in epileptic side compared with normal side, a smaller temporal lobe was resected. Postsurgical MRI was performed 3—6 months after the surgery in 68 patients. The remaining 22 patients refused to have a postsurgical MRI study. Thus, 68 patients were enrolled in the final subjects of investigation. The seizure outcome was determined by the outpatient chart review and telephone contact. The mean postoperative follow-up period was 25.3 ± 7.5 (18—51) months. The subjects were divided into two groups by the postsurgical seizure outcome: SF (seizure-free group, Engel's class I, $N = 54$) and NSF (non-seizure-free group, Engel's class II—IV, $N = 14$).[19]

The presurgical neuropsychological test was performed 1—2 months prior to the operation. The postsurgical follow-up test was performed approximately 1 year after the surgery. Thirty-seven patients in SF group could have both pre- and postsurgical neuropsychological tests. Clinical characteristics registered for each subject included the age of seizure onset, the duration of epilepsy history, the age at surgery, a history of febrile convulsion and the presence of bitemporal interictal spikes on the scalp EEG.

MRI

MRI scanning was performed by a GE Sigma 1.5-T scanner (GE Medical Systems). Spoiled gradient inversion recovery (SPGR) volumetric MRI was scanned with the parameters of no gap, 1.6-mm thickness, 124 slices, repetition time (TR/TE = 30/7 ms, coronal).[20] The SPGR MRI was scanned in 3D mode and the voxel dimension with 0.86 (X) mm $\times$ 0.86 (Y) mm $\times$ 1.6 (Z: slice thickness) mm and without slice overlap. Then, all MRI images were interpolated to the isotropic voxel of 0.86 mm with linear interpolation method. The parameters of coronal oblique fast fluid-attenuated inversion recovery (FLAIR) images was TR/echo time (TE)/TI 10002/127.5/2000, 4 mm thick with 1 mm gap.[20]

The measurement of the resection lengths of hippocampus and lateral temporal gyri

The postsurgical MRI was co-registered to the presurgical MRI by a surface matching algorithm to overlap the pre- and postsurgical brains at the same axis of coordinates (Fig. 1). Image-processing of MRI was performed with Analyze 7.5 software (Biomedical Image Resource, Mayo Foundation, Rochester, MN, USA). Prior to the image analysis, we reconstructed voxel dimension of 0.86 mm $\times$ 0.86 mm $\times$ 1.6 mm to isotropic voxel size (0.86 mm $\times$ 0.86 mm $\times$ 0.86 mm).

The resection length of hippocampus

Brain MRI was reconstructed into 0.86 mm isotropic voxel size and aligned to the AC (anterior commissure)—PC (posterior commissure) line. To determine the length of hippocampus, we inspected three to four sagittal slices visualizing hippocampus well and then selected the best one showing near total hippocampus. The linear length of presurgical hippocampus was measured in parallel with hippocampus from the tip of head to the tip of tail. The entire hippocampus (head, body and tail) was included in the linear length. The linear length of postsurgical hippocampus was measured in the same image number of postoperative MRI (Fig. 2A and B). The resection length of hippocampus was calculated by subtracting length of postsurgical hippocampus from the length of presurgical hippocampus.

To determine whether hippocampus was resected beyond midbrain, the coronal MRI images were inspected serially by comparing the resection margin of hippocampus with the posterior border of midbrain in postsurgical SPGR MRI. The posterior boundary of midbrain was determined when quadrigeminal bodies of the images contacting each other.

The resection lengths of lateral temporal gyri

The whole cerebrum was segmented from the pre- and postsurgical SPGR MRI using a semi-automated technique. The cerebrum was reconstructed by matching the angle and the direction of brain cortex of pre- and postsurgical MRIs using the surface-matching technique and subsequently three-dimensional reconstruction was performed.

For normalization of the resection length of lateral temporal gyri, the presurgical temporal lobe length of each patient was measured. The preoperative MRI was re-sliced to 0.86 mm isotropic voxel size, and then re-sliced MRI was reconstructed into the coronal images perpendicular to the long axis of hippocampus with 0.86 mm isotropic voxel size. The number of slices was counted from the tip

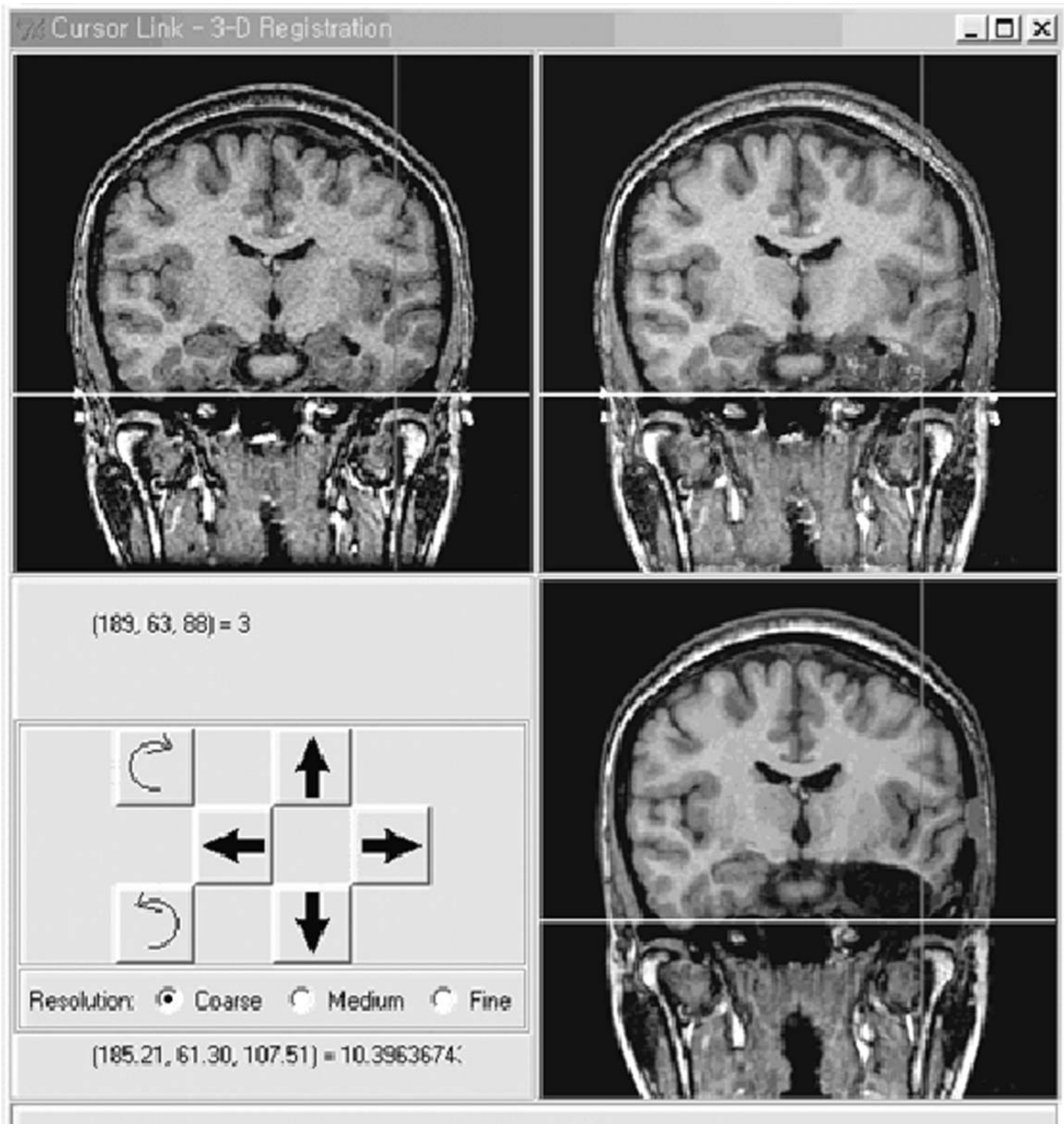

Figure 1 Co-registration of pre- and postsurgical brain MRIs. Using Chamfer surface matching algorithm, postsurgical MRI was registered and transformed to presurgical MRI. Left upper: presurgical MRI; right lower: postsurgical MRI; right upper: overlaid image with pre- and postsurgical MRIs.

of the temporal pole to the posterior boundary where the whole crus of fornix was visualized. The total length of temporal lobe was calculated with multiplying the total slice number of temporal lobe by a voxel size.

A. The resection lengths of the superior and middle temporal gyri (Fig. 2C). The imaginary a-1 line is parallel to Sylvian fissure in the true lateral view on the three-dimensional brain. The imaginary a-2 line is perpendicular to Sylvian fissure at the temporal pole. The resection length of superior temporal gyrus was measured from the anterior margin of superior temporal gyrus to the midpoint of resection margin on the line, which is parallel to a-1 and passes through the middle of superior temporal gyrus. The resection length of middle temporal gyrus was measured by the same method.

B. The resection lengths of the inferior and basal temporal gyri (Fig. 2D). The imaginary b-1 is drawn at the interhemispheric fissure on the basal view of brain. The b-2 is the line connecting right and left temporal poles perpendicular to b-1. The resection lengths of the inferior and basal temporal gyri were measured from the b-2 to the resection margin of the gyrus on the line parallel to b-1.

To clarify the boundary of each temporal gyrus, coronal and parasagittal slices of MRI were demonstrated in Fig. 3.

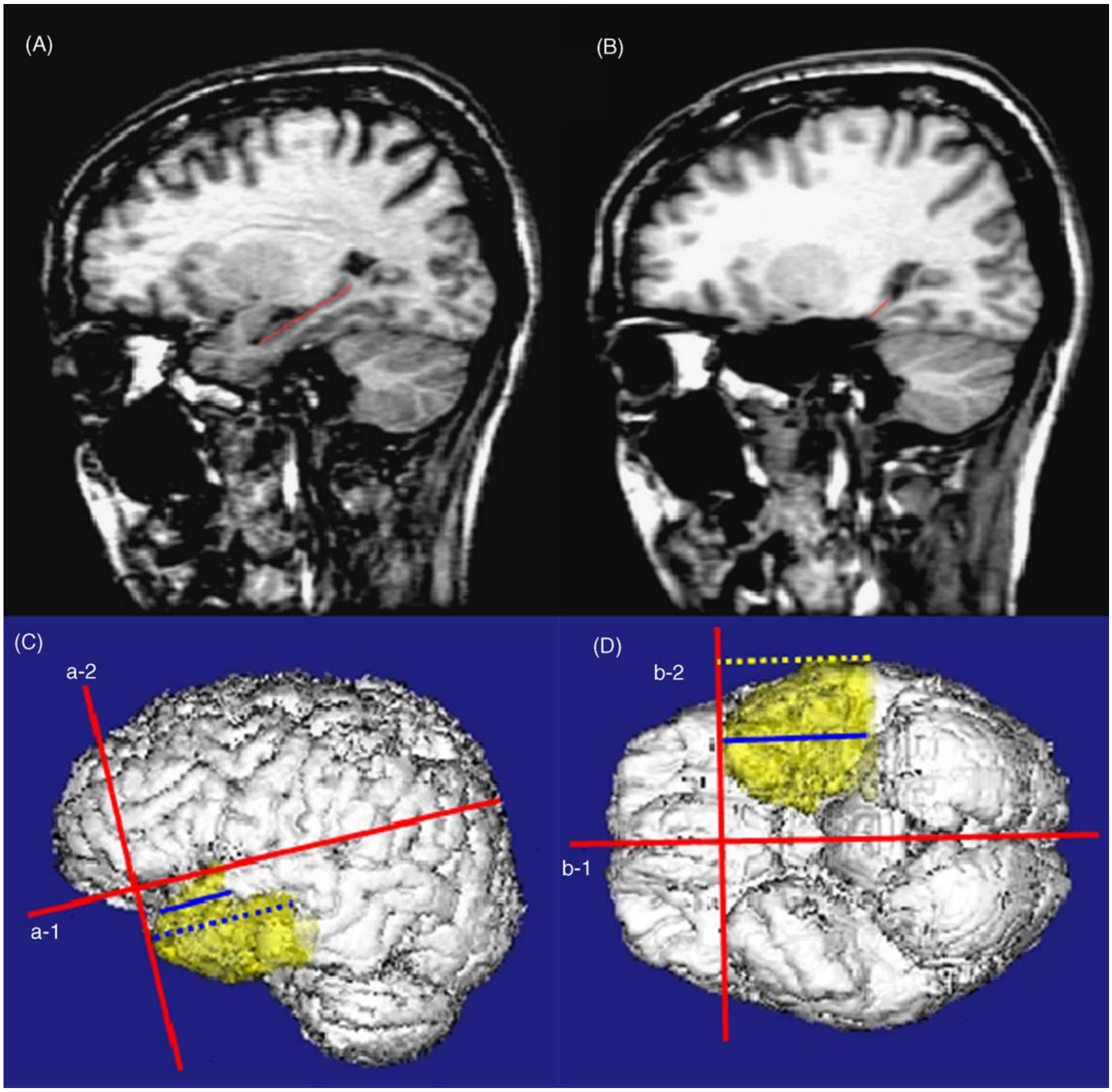

Figure 2 The measurement of resection lengths of hippocampus and lateral temporal neocortex. (A) Preoperative brain sagittal MRI view. Red line indicates a length of preoperative hippocampus. (B) Postoperative brain sagittal MRI view (the same image number as the preoperative MRI after co-registration). Red line is a length of postsurgically remained hippocampus. (C) Lateral view of brain surface: a-1 line is parallel to Sylvian fissure; a-2 line is perpendicular to a-1 line at the temporal pole. Solid blue line indicates a length of resected superior temporal gyrus. Dotted blue line is a length of resected middle temporal gyrus. (D) Basal view of brain surface: b-1 is drawn at the inter-hemispheric fissure; b-2 is a line connecting right and left temporal poles, which should be perpendicular to b-1. Yellow dotted line indicates a length of resected inferior temporal gyrus. Blue solid line is a length of resected basal temporal gyrus.

The resection volume of temporal lobe

The cerebrum was segmented with semi-automated method using pixel intensity-based region growing and manual tracing. The border intensity of gray matter and CSF was decided with the mean value of maximum gray matter intensity value and minimum CSF intensity value. Structural connection with non-cerebral structures was limited by a manual tracing. The intensity values of non-cerebral structures were set to zero. Thereafter, non-zero intensity voxels were automatically counted. Postsurgical cerebral volume was measured by the same criteria of cerebral volume excluding resected temporal lobe. The resection volume of temporal lobe was calculated by subtracting the postsurgical cerebral volume from the presurgical cerebral volume. The resection volume of temporal lobe was normalized by the presurgical cerebral volume.

The extent of hippocampal sclerosis on preoperative brain MRI

One neurologist (E.Y. Joo) and one neuroimage analyst (W.S. Tae) measured the extent of hippocampal sclerosis on preoperative brain FLAIR images in all patients. In coronal FLAIR images perpendicular

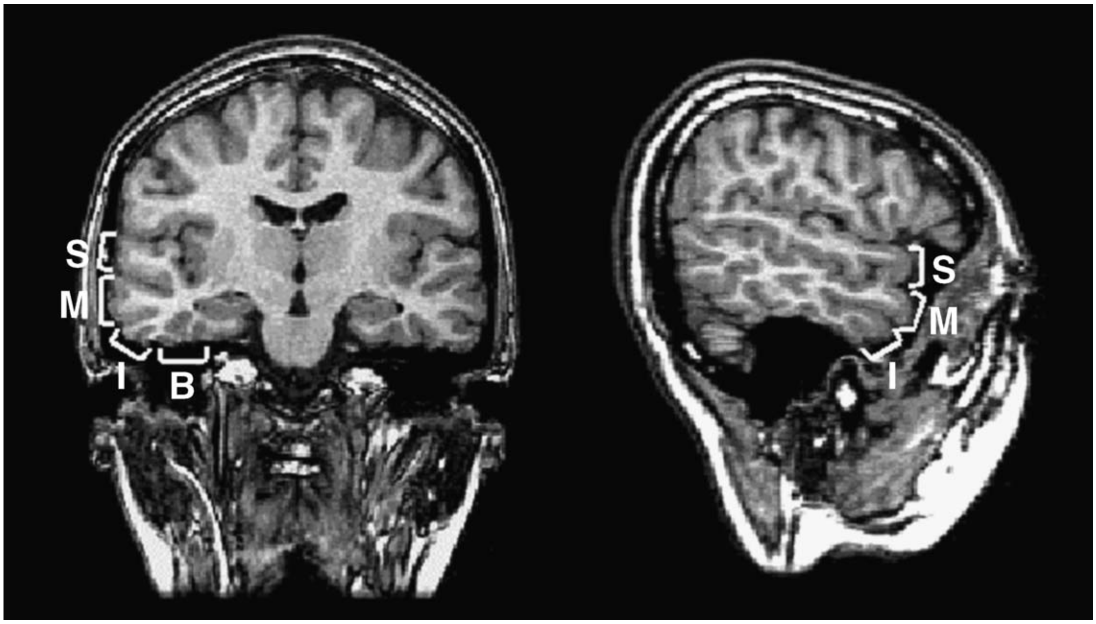

Figure 3 Demarcation of each temporal gyrus. Each bracket demarcates superior (S), middle (M), inferior (I) and basal (B) temporal gyrus in coronal (left) and sagittal (right) MRI images.

to the long axis of hippocampus, the extent of hippocampal sclerosis was defined as a ratio of the number of slices showing increased signal intensity in the hippocampus of epileptogenic hemisphere to the total slice numbers of the whole hippocampus.

Neuropsychological tests

Thirty-seven patients in SF group underwent neuropsychological tests of verbal and visual memory functions presurgically and about 1 year after surgery with the same protocol. Verbal logical memory was assessed with a Korean version of Wechsler Memory Scale—Revised.[14] Visual memory was assessed by Rey complex figure test (RCF).[21,22] The variables in immediate and delayed recalls, and recognition of verbal logical memory test and RCF were evaluated. The postsurgical memory decline (PMD) in each memory variable was calculated by subtracting postsurgical memory score from presurgical one.[21]

Statistical analysis

The numerical data is expressed as the mean (±standard deviation) and was analyzed with Student's *t*-test and chi-square test. Logistic regression analysis was performed to test the correlation of the resection length of hippocampus and the extent of hippocampal sclerosis on FLAIR MRI with surgical outcome. The relationships of resection lengths of hippocampus and lateral temporal gyri with verbal or visual PMDs were tested by Pearson correlation analysis. We tested a relationship of the resection lengths of hippocampus and lateral temporal gyri, the presurgical memory scores, the side of surgery, and Wada memory asymmetry index with verbal or visual PMDs by regression analysis.

The reliability of measurement was tested by the Cronbach's alpha. The *p*-value less than 0.05 was considered significant. All tests were performed using SPSS 10.0.

Results

Patient information

There was no statistical difference of clinical information between SF and NSF: the age of seizure onset, the duration of epilepsy history, the age at surgery, a history of febrile convulsions and the presence of bitemporal interictal spikes on the scalp EEG (Table 1). In pathological examination, 63 of 68 patients had a hippocampal sclerosis [49(90.7%) in SF, 14(100%) in NSF]. Among them, five of SF group had a dual pathology (hippocampal sclerosis + another lesion in mesial temporal lobe; 3 left, 2 right). The remaining five (9.3%) patients of SF group showed the presence of corpora amylacea, few dead neurons in Sommer's sector, and/or partial neuronal loss without the evidence of hippocampal sclerosis in pathology.

The seizure-free rate of all patients in our study was 79.4% (54/68). Those five patients with addi-

Table 1 Clinical information of patients.

	SF (*N* = 54)	NSF (*N* = 14)	*P*[*]
M/F	25/29	6/8	—
Right/left mTLE	31/23	6/8	—
Age of seizure onset (years old)	12.4 ± 7.2	17.2 ± 12.4	0.194
Duration of epilepsy history (years)	13.9 ± 7.6	15.2 ± 7.7	0.616
Age at surgery (years)	26.4 ± 9.0	32.5 ± 14.6	0.169
Febrile convulsion	38.2%	28.5%	0.525
Bitemporal interictal spikes	20.5%	35.7%	0.170

SF: seizure-free group (Engel class I), NSF: non-seizure-free group (Engel class II—IV), M: male, F: female, mTLE: mesial temporal lobe epilepsy.
[*] Student's *t*-test for seizure onset, duration of epilepsy history and age at surgery, chi-square test for the presence of febrile convulsion and bitemporal interictal spikes.

tional lesion had a good surgical outcome (seizure free), too. Seizure-free rate was higher in right TLE without statistical significance [75%, 24/32 in left TLE versus 83.3%, 30/36 in right TLE, $p = 0.385$, Fisher's exact test].

Difference in resection extents of hippocampus and temporal lobe neocortex between seizure-free (SF) and non-seizure-free (NSF) groups

The resection length of hippocampus

The difference of the mean length of presurgical hippocampus between SF and NSF was not statistically significant. The mean resection length of hippocampus in SF, on the other hand, was significantly longer than NSF [32.7 ± 7.7 mm versus 25.1 ± 7.3 mm, $p = 0.002$]. The number of patients with the *complete* resection of hippocampus was 9 in SF (16.7%) and 2 in NSF (14.3%) ($p = 0.829$, chi-square).

The hippocampus was resected beyond the posterior border of midbrain in 23 out of 54 SF patients (42.5%) and 6 out of 14 of NSF (42.8%) ($p = 0.789$, chi-square). However, among patients whose hippocampal resection did not go beyond the midbrain, the mean resection length of hippocampus was longer in SF than NSF.

The result of logistic regression analysis showed that the resection length of hippocampus significantly influenced on seizure outcome [$b = 0.058$, $p = 0.003$] regardless of intersubject difference in the extent of hippocampal sclerosis [$b = 2.842$, $p = 0.081$].

The resection lengths of lateral temporal gyri and the resection volume of temporal lobe

The differences of variables between SF and NSF were tested after the resection lengths of lateral temporal gyri were normalized by the presurgical length of temporal lobe and the resection volume of temporal lobe was normalized by presurgical cerebral volume in each patient. The normalized resection lengths of superior, middle, inferior, and basal temporal gyri and the normalized resection volume of temporal lobe were not significantly different between SF and NSF (Table 2).

The effect of resection extents on postsurgical memory decline (PMD) in SF group

Thirty-seven (18 left TLE and 19 right TLE) patients in SF group underwent a neuropsychological evaluation less than 3 months before surgery and again at about 1 year after surgery. They are all right handedness and language centers were lateralized to left hemisphere in Wada test.

No significant differences were found between pre- and postsurgical verbal and visual memory scores in 37 patients with seizure-free outcome (paired *t*-test, $p > 0.05$).

The verbal and visual PMDs of patients were listed in Table 3. Positive PMD values represent a postsurgical decline of memory score whereas negative PMD values mean a postsurgical increase of memory score. In regression analysis, preoperative verbal or visual memory scores were not significantly related to the verbal or visual PMDs in both left and right TLE patients. However, left-sided surgery was significantly related to PMDs of verbal delayed recall ($b = -9.43$, $p < 0.001$) and verbal recognition ($b = -3.23$, $p = 0.046$) in left TLE patients while right-sided surgery was related to PMD of visual immediate recall ($b = 4.68$, $p = 0.026$) in right TLE patients.

Mean WMS of normal hemisphere in right TLE patients (10.6 ± 1.5) was higher than that in left TLE patients (9.6 ± 1.4) (*t*-test, $p = 0.03$) while mean WMS of epileptic hemisphere was not significantly different between right (5.2 ± 2.3) and left TLE patients (6.6 ± 2.6) ($p = 0.08$). Wada memory asymmetry index was larger in right TLE patients (0.08 ± 0.04) than left TLE patients (0.05 ± 0.04) ($p = 0.02$).

Table 2 The resection extents of hippocampus and temporal lobe neocortex in SF and NSF groups.

	SF (N = 54)	NSF (N = 14)	p
Length of presurgical hippocampus (mm)	40.0 ± 4.1	39.5 ± 4.4	0.691
Length of resected hippocampus (mm)	32.7 ± 7.7	25.1 ± 7.3	0.002*
Length of postsurgically remained hippocampus (mm)	7.3 ± 6.4	14.4 ± 8.9	0.01*
Percentage of resected hippocampus (%)	81.3 ± 16.2	64.5 ± 21.4	0.01*
Resected temporal lobe volume (mm^3) (normalized ratio)	32404.5 ± 11280 (0.03 ± 0.01)	34846.0 ± 14452 (0.03 ± 0.01)	0.49 (0.56)
Length of resected superior temporal gyrus (mm) (normalized ratio)	20.1 ± 11.0 (0.33 ± 0.18)	15.0 ± 12 (0.24 ± 0.18)	0.20 (0.12)
Length of resected middle temporal gyrus (mm) (normalized ratio)	32.0 ± 13.1 (0.53 ± 0.21)	32.2 ± 12.2 (0.53 ± 0.19)	0.97 (0.99)
Length of resected inferior temporal gyrus (mm) (normalized ratio)	63.3 ± 20.1 (1.05 ± 0.33)	74.2 ± 23.0 (1.22 ± 0.32)	0.11 (0.08)
Length of resected basal temporal gyrus (mm) (normalized ratio)	61.5 ± 15.5 (1.01 ± 0.23)	61.0 ± 9.3 (1.00 ± 0.11)	0.90 (0.88)

Values are mean extent, % or volume. Percentage of resected hippocampus = (the length of resected hippocampus/the length of presurgical hippocampus) × 100%. Normalized ratio (of resected temporal lobe volume) = [resected temporal lobe volume/presurgical cerebral volume]. Normalized ratio (of resected temporal gyrus) = [the length of resected temporal gyrus/the preoperative length of whole temporal lobe]. SF: seizure-free group (Engel class I); NSF: non-seizure-free group (Engel class II—IV).

* $p < 0.05$, Student's t-test.

In left TLE patients, the resection length of inferior or basal temporal gyrus showed a positive correlation with the verbal PMD regardless of interpersonal difference in Wada memory asymmetry index. The resection length of inferior temporal gyrus was significantly correlated with PMD of verbal immediate recall (Pearson correlation, $r = 0.791$, $p < 0.001$; regression analysis, $b = 1.00$, $p < 0.001$). The resection length of basal temporal gyrus was correlated with PMD of the verbal delayed recall (Pearson correlation, $r = 0.845$, $p < 0.001$; regression analysis, $b = 1.00$, $p < 0.001$) and PMD of verbal recognition (Pearson correlation, $r = 0.586$, $p = 0.01$; regression analysis, $b = 1.00$, $p < 0.001$).

Table 3 The postsurgical memory decline in left and right TLE patients.

Variables	Left TLE (N = 18)	Right TLE, (N = 19)
Logical (verbal) memory		
Immediate	0.49 ± 5.3	-1.05 ± 4.5
Delayed	0.44 ± 5.4	-4.00 ± 5.6
Recognition	0.28 ± 2.8	1.21 ± 5.0
Visual memory		
Immediate	-0.33 ± 5.3	-0.32 ± 5.2
Delayed	-0.22 ± 5.1	-0.37 ± 5.7
Recognition	0.06 ± 1.9	1.16 ± 4.5

TLE: temporal lobe epilepsy. All subjects have been seizure free after the surgery (SF group). Numerical values of cells represent the mean ± standard deviation of postsurgical memory decline (presurgical memory score − postsurgical memory score).

The resection lengths of hippocampus, superior and middle temporal gyri and the resection volume of temporal lobe were not significantly correlated with verbal or visual PMDs.

In contrast, right TLE patients showed no significant correlation of the resection length of hippocampus or temporal gyri or the resection volume of temporal lobe with verbal or visual PMDs.

Reliability of measurement

All the analyses were performed by one image analyst (W.S. Tae), who was blinded to subject identity. For estimation of the intra-rater reliability, all measurements were repeated in a random order. Intra-rater reliability showed a high concordance rate in all measurements of extents of resection (temporal lobe volume: $\alpha = 0.95$, hippocampal length: $\alpha = 0.94$, superior temporal gyrus: $\alpha = 0.92$, middle temporal gyrus: $\alpha = 0.97$, inferior temporal gyrus: $\alpha = 0.93$, and basal temporal gyrus: $\alpha = 0.96$, Cronbach's alpha).

Discussion

We measured the resection lengths of the hippocampus and the lateral temporal gyri by MRI reconstruction method and evaluated the relationship of the resection lengths with postsurgical seizure outcome and memory changes.

Several studies reported that the resection extent of the mesial temporal structure positively correlates to the outcome of the surgery,[2—4,15,23] which is concordant to our result. Another study reported that two types of surgery (selective amygdalohippocampectomy versus anterior temporal lobectomy with amygdalohippocampectomy) were equally effective in the postoperative seizure outcome, which suggested the relative low role of lateral temporal neocortex in postoperative seizure outcome.[24]

Our data shows that the resection length of hippocampus in SF is significantly longer than NSF. Logistic regression analysis showed that resection length of hippocampus significantly influenced on the seizure outcome regardless of intersubject difference in the extent of hippocampal sclerosis on FLAIR MRI. These findings suggest that the greater resection of epileptic hippocampus results in the better postsurgical seizure outcome. This is in agreement with the results reported by others.[6,25,26] When the amount of lateral cortical resection was the same, the group underwent total hippocampal resection had a statistically superior seizure outcome compared with the partial hippocampectomy group.[23] In contrast, some studies demonstrated that the extent of hippocampal resection had no effect on the postoperative seizure outcome. Feindel and Rasmussen[5,6] compared postsurgical seizure outcome in 100 patients with minimal hippocampal resection versus another 100 patients with half or more of hippocampal resection. They determined the removal of the pes plus half or more of the body in hippocampus as the maximal hippocampectomy and the removal less than of the anterior half of the pes as the minimal hippocampectomy in view of operation field but did not verify the resection extent in postsurgical MRI.

Another study recommended that to achieve the seizure control, the mesiobasal resection of the temporal lobe should be extended posteriorly as far as to the anterior half of the mesencephalon.[4] But it is difficult to determine whether the posterior resection margin of the hippocampus passed the anterior half of the mesencephalon in MRI images. We, thus, determined whether the hippocampus was resected beyond the posterior border of the midbrain in MRI images. In our result, the resection of hippocampus extended beyond the posterior border of midbrain in 23 of 54 (42.6%) in SF and 6 of 14 (42.9%) in NSF, which were not different between two groups. This finding suggests that hippocampal resection beyond the midbrain is not a prerequisite for a good surgical outcome. Nonetheless, among patients whose hippocampal resection was not beyond the midbrain, the resection length of hippocampus was longer in SF than that in NSF (32.3 ± 7.9 mm in SF versus 23.1 ± 7.0 mm in NSF, Mann–Whitney *U*-test, $p = 0.004$,).

Our data shows that the differences in resection lengths of lateral temporal gyri and the resection volume of temporal lobe between SF and NSF are not statistically significant. Lateral and basal temporal cortices were re-evaluated by intraoperative ECoG after temporal lobectomy. If the epileptiform discharges were actively recorded in remaining areas, tailored resection was performed without compromise to functional areas. There is no consensus concerning which structures, or how much of any one structure, should be removed for optimal seizure control. It was reported that selective amydalohippocampectomy was as effective as anterior temporal lobectomy with amygdalohippocampectomy in the postsurgical seizure outcome.[24] In our study, the resection lengths of lateral temporal gyri were not different between SF and NSF, which suggests that the resection extent of lateral temporal neocortex may not be an important factor in determining the seizure outcome of surgery if ECoG-guided irritative zone is removed.

Several methods have been applied to measure the extent of the temporal lobe.[3,15] The new 20-compartment model divides the temporal lobe into four quadrants based on the five coronal planes of the postoperative MRI.[3,16] The extent of the resection in each quadrant was graded semi-quantitatively as 0 = no resection, 1 = partial resection and 2 = complete resection. The extent of resection in each quadrant was averaged and compared among patients. The limitation of this method is only three grading systems with a wide range of partial resection and the subjective determination of resection extent.

Another study co-registrated the preoperative MRI with the postoperative MRI and then divided the temporal lobe into six substructures: (1) hippocampus, (2) amygdala, (3) parahippocampal gyrus, (4) medial occipitotemporal gyrus, (5) superior temporal gyrus and (6) lateral occipitotemporal/inferior temporal/middle temporal gyri.[15] They measured the volumes of the compartments by a manual delineation for each case and calculated the resected volume by pixel counting. This method could re-locate pre- and postsurgical brain MRI images of the same patient performed in different times and head positions to the same three-dimensional coordinate. But they measured the resection volumes of different compartments while we measured resection lengths of mesial and lateral temporal structures.

We applied the co-registration and the surface-rendering techniques of pre- and postsurgical MRIs to measure the resection lengths of hippocampus and each temporal gyrus and the resection volume of temporal lobe. To measure the hippocampal resection length, the pre- and postsurgical brain MRIs were co-registered and the sagittal image showing the longest axis of hippocampus was selected in pre- and postsurgical SPGR MRI. This method allows measurement of the linear length of the hippocampus consistently because the direction and axis of postsurgical hippocampus were adjusted to presurgical hippocampus. We measured the resection lengths of lateral temporal gyri using Chamfer surface-rendering technique that shows the detail expression of the gyral surface in temporal lobe, which permits to clearly distinguish the superior, middle and inferior temporal gyri. The co-registration between the pre- and postsurgical MRIs allows to re-orient the pre- and postsurgical images to the same three-dimensional coordinate. This minimizes the measurement errors originated from the pre- and postsurgical brain MRI images with different head positions during scanning. Our method may provide the real resection lengths of lateral temporal gyri.

All NSF and most SF patients (45 of 54 patients, 83.3%) had been taking the previous AEDs with same doses or minimal tapering-off and nine of SF patients were completely quit the AEDs at the time of classification of seizure outcome. So, the AED of the patients did not appear to influence on the determination of seizure outcome.

Although overall postsurgical memory scores were not significantly changed compared to presurgical ones, the resection length of inferior or basal temporal gyrus showed a significant positive correlation with the verbal PMDs regardless of intersubject difference in Wada memory asymmetry index in left TLE patients. These findings suggest that greater resection of left inferior or basal temporal gyri in left TLE patients is more likely to produce postsurgical verbal memory decline. However, the resection length of hippocampus was not related to verbal or visual PMDs in left or right TLE patients.

The temporal neocortex are assumed to mediate short-term or working memory and to provide a repository of stored information.[27] The lateral neocortex of the dominant hemisphere is involved in verbal short-term memory.[28] Our result showed that left-sided surgery was significantly related to verbal PMD while right-sided surgery was related to visual PMD regardless of intersubject difference in the extent of hippocampus resection. This finding supports the concept that the temporal neocortex of dominant hemisphere is involved in verbal memory while the temporal neocortex of non-dominant hemisphere is connected with visual memory.

One study demonstrated that the extent of hippocampal resection (partial versus total) was not associated with significant pre- to postoperative change on any verbal memory index in left TLE patients.[23] But they did not investigate the effect of lateral temporal resection on postsurgical memory changes.

Previous studies showed that postsurgical verbal memory decline is related to the resection of lateral temporal cortex which support our result.[29,30] One study modified the medial extent of the resections in consideration of a Wada memory result and intraoperative monitoring of language and verbal memory was also performed by electrical stimulation mapping.[29] They found that memory decline was greater in patients who were not seizure free, and correlated with the lateral extent (but not the medial) of the resection. In the other study, the authors resected the left two-third anterior temporal lobe and found that the extent of the en bloc resection is a valuable determinant of postoperative changes in acquisition and recognition of verbal memory.[30] But our study measured the resection length of each temporal gyrus and suggests that the verbal memory decline after the left temporal lobectomy may be related to the larger resection of the inferior or basal temporal gyri.

Conclusion

The greater resection of epileptic hippocampus may predict the better postsurgical seizure outcome whereas the resection extent of lateral temporal gyri was not correlated with the postsurgical seizure outcome. Overall postsurgical changes of verbal or visual memory scores were not significant in 37 TLE patients with seizure free after surgery. However, the resection length of inferior or basal temporal gyrus was correlated with the postsurgical verbal memory decline in left TLE patients.

Acknowledgement

This study was supported by a grant (no. A050462) of the Good Health R&D Project, Ministry of Health & Welfare, Republic of Korea.

References

1. Hauser W. The natural history of temporal lobe epilepsy. In: Luders HO, editor. *Epilepsy surgery*. New York: Raven Press; 1991. p. 133—41.
2. Kuzniecky R, Burgard S, Faught E, Morawetz R, Bartolucci A. Predictive value of magnetic resonance imaging in temporal lobe epilepsy surgery. *Arch Neurol* 1993;**50**:65—9.
3. Awad IA, Katz A, Hahn JF, Kong AK, Ahl J, Luders H. Extent of resection in temporal lobectomy for epilepsy. I: Interobserver

analysis and correlation with seizure outcome. *Epilepsia* 1989;**30**:756—62.
4. Nayel MH, Awad IA, Luders H. Extent of mesiobasal resection determines outcome after temporal lobectomy for intractable complex partial seizures. *Neurosurgery* 1991;**29**:55—61.
5. Rasmussen T, Feindel W. Temporal lobectomy: review of 100 cases with major hippocampectomy. *Can J Neurol Sci* 1991;**8**: 601—2.
6. Feindel W, Rasmussen T. Temporal lobectomy with amygdalectomy and minimal hippocampal resection: review of 100 cases. *Can J Neurol Sci* 1991;**18**:603—5.
7. Saling MM, Berkovic SF, O'Shea MF, Kalnins RM, Darby DG, Bladin PF. Lateralization of verbal memory and unilateral hippocampal sclerosis: evidence of task-specific effects. *J Clin Exp Neuropsychol* 1993;**15**:608—18.
8. Miller LA, Munoz DG, Finmore M. Hippocampal sclerosis and human memory. *Arch Neurol* 1993;**50**:391—4.
9. Tran TA, Spencer SS, Marks D, Javidan M, Pacia S, Spencer DD. Significance of spikes recorded on electrocorticography in nonlesional medial temporal lobe epilepsy. *Ann Neurol* 1995; **38**:763—70.
10. Cascino GD, Trenerry MR, Jack Jr CR, Dodick D, Sharbrough FW, So EL, et al. Electrocorticography and temporal lobe epilepsy: relationship to quantitative MRI and operative outcome. *Epilepsia* 1995;**36**:692—6.
11. Spencer DD, Spencer SS, Mattson RH, Williamson PD, Novelly RA. Access to the posterior medial temporal lobe structures in the surgical treatment of temporal lobe epilepsy. *Neurosurgery* 1984;**15**:667—71.
12. Hardiman O, Burke T, Phillips J, Murphy S, O'Moore B, Stauton H, et al. Microdysgenesis in resected temporal neocortex: incidence and clinical significance in focal epilepsy. *Neurology* 1988;**38**:1041—7.
13. Hermann BP, Wyler AR, Bush AJ, Tabatabai FR. Differential effects of left and right anterior temporal lobectomy on verbal learning and memory performance. *Epilepsia* 1992; **33**:289—97.
14. Kwon OD, Kim JE, Kim JS, Yi SD. Memory function in patients with mesial temporal lobe epilepsy. *J Korean Neurol Assoc* 2001;**19**:116—24.
15. Moran NF, Lemieux L, Maudgil D, Kitchen ND, Fish DR, Shorvon SD. Analysis of temporal lobe resections in MR images. *Epilepsia* 1999;**40**:1077—84.
16. Kanner AM, Kaydanova Y, de Toledo-Morrell L, Morrell F, Smith MC, Bergen D, et al. Tailored anterior temporal lobectomy. Relation between extent of resection of mesial structures and postsurgical seizure outcome. *Arch Neurol* 1995;**52**:173—8.
17. Lee HW, Hong SB, Kim KW, Han SH, Seo DW, Lee WY, et al. Predictive values of four Wada memory asymmetry indices in postsurgical memory outcome. *J Korean Neurol Assoc* 1998; **16**:839—43.
18. Joo EY, Lee EK, Tae WS, Hong SB. Unitemporal vs. bitemproal hypometabolism in mesial temporal lobe epilepsy. *Arch Neurol* 2004;**61**:1074—8.
19. Engel J. Outcome with respect to epileptic seizures. In: Engel Jr J, editor. *Surgical treatment of the epilepsies*. New York, NY: Raven Press; 1987. p. 553—71.
20. Tae WS, Hong SB. Sexual dimorphism of human corpus callosum using quantitative MRI. *J Korean Neurol Assoc* 2002; **20**:34—42.
21. Tupler LA, Welsh KA, Asare-Aboagye Y, Dawson DV. Reliability of the Rey-Osterrieth complex figure in use with memory-impaired patients. *J Clin Exp Neuropsychol* 1995;**17**:566—79.
22. Meyers JE, Meyers KR. *Rey complex figure test and recognition trial: professional manual*. Odessa: Psychological Assessment Resources, Inc.; 1995.
23. Wyler AR, Hermann BP, Somes G. Extent of medial temporal resection on outcome from anterior temporal lobectomy: a randomized prospective study. *Neurosurgery* 1995;**37**: 982—90.
24. Arruda F, Cendes F, Andermann F, Dubeau F, Villemure JG, Jones-Gotman M, et al. Mesial atrophy and outcome after amygdalohippocampectomy or temporal lobe removal. *Ann Neurol* 1996;**40**:446—50.
25. Tae WS, Lee EK, Joo EY, Seo DW, Hong SB. Volume changes of frontal lobe and hippocampus in juvenile myoclonic epilepsy. *J Korean Neurol Assoc* 2003;**21**:54—61.
26. McMackin D, Stauton H. Surgery for temporal lobe epilepsy: a review. *J Jr Coll Physicians Surg* 1991;**20**:193—7.
27. Halgren E, Physiological integration of the declarative memory system.Delacour J, editor. *The memory system of the brain Advances in neuroscience*, vol. 4. Singapore: World Scientific Publishing Co. Pte. Ltd.; 1994. p. 1—69.
28. Pauli E, Pickel S, Schulemann H, Buchfelder M, Stefan H. Neuropsychologic findings depending on the type of the resection in temporal lobe epilepsy. *Adv Neurol* 1999;**81**: 373—7.
29. Ojemann GA, Dodrill CB. Verbal memory deficits after left temporal lobectomy for epilepsy: mechanism and intraoperative prediction. *J Neurosurg* 1985;**62**:101—7.
30. Helmstaedter C, Elger CE. Cognitive consequences of two-thirds anterior temporal lobectomy on verbal memory in 144 patients: a three-month follow-up study. *Epilepsia* 1996;**37**: 171—80.